BEBR

FACULTY WORKING
PAPER NO. 1451

Adoption of High Yielding Rice Varieties in Bangladesh: An Econometric Analysis

Anil K. Bera
Timothy G. Kelley

College of Commerce and Business Administration
Bureau of Economic and Business Research
University of Illinois, Urbana-Champaign

BEBR

FACULTY WORKING PAPER NO. 1451

College of Commerce and Business Administration

University of Illinois at Urbana-Champaign

May 1988

Adoption of High Yielding Rice Varieties in Bangladesh: An Econometric Analysis

Anil K. Bera, Professor
Department of Economics

Timothy G. Kelley
Agricultrual Economics

April, 1988

ADOPTION OF HIGH YIELDING RICE VARIETIES IN BANGLADESH: AN ECONOMETRIC ANALYSIS

Anil K. Bera*
Dept of Economics
University of Illinois

Timothy G. Kelley
Dept of Agricultural Economics
University of Illinois

ABSTRACT

In this paper we build two logistic type econometric models to explain HYRV diffusion rate in Bangladesh. Long run potentials (ceiling), diffusion rates, and the effects of other economic variables on the adoption path are determined simultaneously within the model. Results from our final model indicate that the diffusion rate is not constant over time. Furthermore, rate and level of adoption are found to be influenced by flood damage, jute-rice price ratio and HYRV-local rice variety price ratio. An important outcome of our analyses is that the ceiling adoption level for Bangladesh has nearly been reached. Unless new HYRVs are developed with wider adaptability, especially for drought and flood prone areas, little scope exists for production increases through HYRV acreage expansion. This conclusion has significant policy implications for agricultural planners and development agents in Bangladesh.

*Anil K Bera, Dept of Economics, University of Illinois, 1206 S. 6th Street, Champaign, IL 61820

1. Introduction

The International Rice Research Institute (IRRI) released a short-statured, fertilizer-responsive rice variety as early as 1965 (IR-8). Yet it was not until the mid to late seventies that widespread adoption of modern High Yielding Rice Varieties (HYRVs) occurred in Asia. Nonetheless, by 1979, well over half of the rice growing areas in South and Southeast Asia were planted to HYRVs. This had an enormous impact on raising rice production levels in Asia. Some countries which were formerly heavily dependent on food grain imports subsequently became self sufficient, such as, Indonesia and the Philippines. But not all countries have shared this experience: Bangladesh is one such case.

Of the major rice growing countries in Asia, only Thailand has a lower rate of adoption of HYRVs than Bangladesh [Dalrymple (1986)]. At present, HYRVs occupy just 27 percent of the total rice growing area of Bangladesh. Although it is third only to China and India in acreage planted to rice (25.9 million acres), production per acre is one of the lowest in Asia (0.65 tons/acre, compared to say, Indonesia, with average yields of 1.75 tons/acre). Low rice productivity explains in part why Bangladesh continues to suffer from chronic shortfalls in foodgrain supply and why food availability per capita is one of the lowest in the world.

These facts are important when considering that HYRVs have the potential of doubling or even tripling rice yields over those

of the traditional (local) varieties. In view of this, more widespread adoption of HYRVs is considered an essential component in the Government's strategy of raising total rice production to achieve total food grain self sufficiency by 1990 [Ministry of Planning, Government of Bangladesh (1985)].

It remains to be asked, however, whether further adoption of HYRVs in Bangladesh is possible? To answer this question it is important to know the economic and natural factors that influence adoption rates. It can then be determined when (if not already) the maximum potential acreage under HYRVs will be realized. Furthermore, the areas that will provide the greatest scope for expansion can be identified.

In this paper, we build two logistic type econometric models to explain aggregate HYRV diffusion rates in the transplanted aman crop (t.aman)[1] of Bangladesh, covering the period from 1971

---

[1] The three main types of rice grown in Bangladesh, defined according to the season in which they are planted, are aman, aus and boro. Aman is either broadcasted (b.aman) or transplanted (t.aman). If broadcasted, it is planted during March or April in lowland or basin areas where water depth exceeds one meter. Currently, no HYRVs exist for b.aman areas. T.aman, which generally occupies higher land types, is transplanted from nursery seedbeds into flooded fields usually between July and August. Both b.aman and t.aman are harvested in November or December after the waters have receded. Aus rice precedes the sowing of t.aman and accounts for approximately 27 percent of the rice growing area. It also competes with jute, the main cash crop and primary export commodity of Bangladesh. Boro rice is grown during the dry winter season (December-April) in lowland or basin areas. It accounts for approximately 16 percent of the rice growing area. T.aman accounts for about 45 percent of the total rice area (and production), thus making it the most important of the three. For this reason, and because it has the environment best suited to current HYRVs, t.aman offers the largest potential for increased production through adoption of HYRVs.

to 1985. Standard econometric model specification tests and non-nested hypothesis test procedures are used in selecting a final model. Long-run potentials, diffusion rates, and the effects of other variables on the adoption paths are determined simultaneously within the models. Regional analyses are carried out to identify the areas which provide the greatest potential for HYRV acreage expansion.

2. Effects of Agroclimatic Conditions

An especially important reason for non-adoption of HYRVs is their lack of adaptability and resilience compared with the local varieties in the face of commonly-occurring, adverse climatic events. The taller traditional local varieties are renowned for their ability to escape from, or at least tolerate, both the seasonal floods and recurring droughts. The ability of some traditional deepwater aman varieties to elongate their stem with advancing flood waters, thereby escaping complete submergence, is perhaps the classic case. Many traditional varieties have similar, if less dramatic, built-in mechanisms that assure minimum yields under a wide range of flood and drought conditions[2] (see Figure 1). HYRVs, on the other hand, are much more limited in their adaptability to those conditions, largely due to their shorter stature, yet demanding water requirements.

---

[2] Other advantages cited for traditional varieties include such things as longer length and yield of straw (used for thatch roofing, cattle fodder and fuel), greater ability to compete with weeds and insects pests, and superior quality of grain.

They are adapted mainly to the medium highland and highland land types which generally, but not always, are located at flood-free levels.

For these reasons, HYRVs have not been able to transfer freely across agroclimatic zones. Some parts of Bangladesh (with adequate water control, or at higher elevation) are suitable for modern varieties, but the vast majority of the country may not be appropriate for HYRVs due to problems associated with either flooding or drought.

Final adoption has been defined as the "degree of use of a new technology in long-run equilibrium when farmers have full information about the new technology and its potential" [Feder et al. (1985) p. 256]. It is reasonable to ask, and important to know, whether the long-run equilibrium (i.e. final adoption) of such a productive technology like HYRVs has yet been reached. Stated simply, has the acreage under HYRV of t.aman in Bangladesh attained its maximum potential? And if potential for HYRV acreage expansion exists, in which regions of Bangladesh is it likely to occur? Furthermore, what, if anything, can be said about the rate of HYRV adoption in Bangladesh, and what variables play a role in characterizing this process? These questions will be investigated in the following sections.

3. The Logistic Function Approach

Previous empirical and theoretical research indicated that the logistic curve or the S-shaped diffusion path characterizes

fairly well the adoption pattern of new agricultural technologies [Griliches (1957), Feder and O´Mara (1982), Jarvis (1982) and Rogers (1983)]. According to the hypothesis, when new technology is first introduced, diffusion is slow. Through the process of "demonstration effects" generated by the early adopters (the most progressive), diffusion increases rapidly as information and experience spreads to other producers. Eventually, after all of the potential adopters have been exposed to and adopted the new technology, a long-run equilibrium is reached. The logistic function traces out this path and defines the rate of adoption and the long-run equilibrium, i.e., a ceiling value.

In his pioneering paper, Griliches (1957) estimated the percentage of land planted to hybrid corn using a logistic function. It was probably the first econometric study of aggregate adoption over time. He used the logistic growth curve

$$P_t = \frac{K}{1 + \exp-(\alpha + \beta t)} \qquad (1)$$

where P_t is the percent acreage planted to hybrid corn at time t, K is the long-run equilibrium value (ceiling), β is a measure of the rate of acceptance of the new technology (slope), and α, reflects adoption at the initial period (origin). The logistic model is based on the assumption that the diffusion rate at a given point in time is proportional to the remaining distance of some predetermined saturation level, K, and to the currently attained diffusion level; as seen by

$$\frac{dP_t}{dt} = \beta P_t \frac{K-P_t}{K}$$

In terms of relative growth rate, we have

$$\frac{1}{P_t}\frac{dP_t}{dt} = \beta \left(1 - \frac{P_t}{K} \right) \qquad (2)$$

That is, relative growth rate gradually decreases as P_t increases. This is a plausible assumption given that P_t has an upper limit.

Griliches found variation in the parameters of the diffusion curve across the geographical regions. A significant amount of the variation observed in ceiling level (K), origin (α), and slope (β), could be explained by factors such as market size, corn acreage per farm, and profitability differentials between the districts. Thus, Griliches´ study was a two step cross sectional analysis. Parameters in the logistic function for each region were first estimated and regional parameter estimates were then regressed on these specific economic variables.

Jarvis (1982) took a slightly different approach and used a modified logistic function to estimate and predict aggregate adoption of improved pastures in Uruguay. Beef and fertilizer prices were incorporated into the logistic function, together serving as a proxy for relative profitability. Both variables were found to affect the slope (rate of acceptance) and the saturation level of adoption. Thus while Griliches used observed

economic variables (such as profitability) to explain regional differences in parameters defining the logistic function, Jarvis used economic variables by incorporating them into a simple logistic expression, thus deriving a modified logistic function. This modification recognizes that certain factors, namely prices associated with the relative profitability of a new technology, will often distort the aggregate adoption curve away from the simple logistic pattern. For other work on the use of the logistic curve, see the survey paper of Feder et al. (1985).

4. Limitation of the Logistic Model

Our aim is to find an appropriate function to describe the aggregate adoption curve for HYRV t.aman in Bangladesh and its four regions[3], for the period 1971-1985. Data[4] related to percent t.aman acreage in HYRV for the East, Central, Southwest and Northwest regions of Bangladesh are presented in Table 1 and Figure 2. It is apparent that the regional curves deviate rather substantially from the simple logistic or conventional S-shaped

---

[3] The four regions are each comprised of four districts, grouped according to their geographical proximity, topography and similar adoption rates. The East Region consists of Chittagong, Chittagong Hill Tracts, Comilla and Noakhali; the Central Region: Dhaka, Faridpur, Mymensingh and Kishoregong; the Southwest Region: Barisal, Jessore, Khulna, and Khustia; and the Northwest Region: Bogra, Dinajpur, Rajshahi and Rangpur. Only four districts (Sylhet, Tangail, Patuakhali and Pabna) have been excluded from the analysis, due to their very negligible adoption rates.

[4] Data for this study came primarily from the Agricultural Yearbook of Bangladesh for the years 1981-82 and 1983-84, and from Monthly Statistical Bulletins of Bangladesh (March, 1973; 1976; 1979; 1982; 1984; 1986).

diffusion path. The distortion appears largest in the initial years. However, the curve resumes an S-shaped pattern during the later years.

Estimation of the logistic function in (1) was carried out using unrestricted nonlinear regression techniques with SHAZAM Package. Different starting values for each of the coefficients were tried to ensure global optimality. Results of fitting a simple logistic function to the data are given in Table 2. Only the East region appeared to follow the logistic pattern. The nonlinear iteration process did not converge for the Southwest and Northwest regions even after 300 iterations. For the Central region and Bangladesh, although convergence obtained, the fits seemed to be poor. These results were not unexpected given the divergence of observed adoption pattern of the different regions and Bangladesh from the ideal logistic curve in Figure 2.

The logistic expression fails to account for the early dramatic rise and then sudden fall in the aggregate adoption rate (from 1971 to 1975-6), and this leads to the poor fit. In the aggregate adoption studies of Griliches and Jarvis, technology is such that the cumulative distribution of the diffusion process is always an increasing, or non-decreasing, function[5]. No allowance is made for rejecting the technology after once accepting it, at

---

[5] Less production uncertainty and continual development (and modification) of new environment-specific hybrids explains the non-decreasing function in Griliches' study. In the Jarvis study, decisions made about acreage under improved pasture are not independent from year to year due to high structural costs associated with returning the pasture to "non-improved" status.

least at the aggregate level. For adoption of HYRVs in Bangladesh, however, the situation is somewhat different: choice of whether to adopt the new technology, especially in the early years of exposure, is relatively independent from one year to the next. Expectations about adverse climatic events, eg., floods, and the resultant uncertain responses of HYRVs, may indeed result in a reversal in the adoption process. Other studies have shown similar tendencies [Leuthold (1967), Diamante and Alix (1974)]; and Rogers (1983) has defined this behavior as "disenchantment discontinuance".

It is evident from Figure 2 that such a phenomenon occurred on a wide scale (in <u>every</u> region) after 1973. This "disenchantment discontinuance" was so prominent that, for the country as a whole, HYRV t.aman acreage dropped by more than 40 percent between 1973 and 1974. Acreage planted to HYRV t.aman did not recover to its 1973 level until 1980. Any function which attempts to describe the aggregate adoption curve will have to account for this significant drop in adoption.

5. Modified Logistic Models

To find an appropriate adoption curve, it is natural to start with our earlier logistic function and modify it. The logistic function (1) can be written as

$$\ln\left(\frac{P_t}{K - P_t}\right) = \alpha + \beta t$$

or

$$\ln \left(\frac{p_t}{1 - p_t} \right) = \alpha + \beta t \qquad (3)$$

where $p_t = P_t/K$. Given that P_t is the current adoption rate and K is its ceiling, p_t can be viewed as the probability of adopting HYRV among all potential adopters since

$$p_t = P_t/K = \frac{\text{acreage planted to HYRV}}{\text{total area which eventually will be under HYRV}}$$

Also note that $0 \leq p_t \leq 1$. Right hand side of (3) is the familiar form for the logit model. In the logit model this is expressed as a linear function of all the variables that affect the individual's choice, i.e., whether to plant traditional variety or HYRV. In the logistic model (1), i.e., in model (3) above, time t is the only explanatory variable. It is unlikely, however, that a simple time trend can explain the diffusion process. From the discussion in Section 2, it is clear that there are variables relating to the agroclimatic conditions which affect the individual farmer's decision process, and, which in turn, affect the aggregate adoption rate.

Let us write

$$\ln \left(\frac{p_t}{1 - p_t} \right) = x_t{}'\beta$$

where the x_t are the set of exogenous variables including time t,

and an intercept; and the ß is the corresponding parameter vector. Our modified logistic function, therefore, becomes

$$P_t = \frac{K}{1 + \exp-(x_t{'}\beta)} \tag{4}$$

Given our very limited data set, we are restricted in the number of variables that can be used in the model. Therefore, it requires a judicious choice among a host of variables and attributes, such as prices, relative profitability, learning, flood damage, government incentive, availability of seeds and fertilizer, etc. The following discussion will be concentrated on selection of variables from the economic point of view, and again, the main question we ask is which variables affect the farmer´s decision process most.

It is well recognized that adverse climatic occurrences, especially floods, play a major role in determining crop and varietal choice in Bangladesh [FAO (1984)]. Because of their specific effects on rice production decisions, it seems reasonable to incorporate an agro-climatic variable into the model. The hypothesis presented here is that the "overadoption" observed in the initial years (1971-1973) was the result of a general over-expectation on the part of producers-- based on incomplete knowledge about the performance of HYRVs within various agro-climatic environments, and specifically, under abnormal flood conditions. In 1973, floods occurring in July, August and September, virtually all over the country, caused

enormous damage to the t.aman crop. Over 1,500,000 acres of t.aman was partially or completely damaged; the single worst production loss in t.aman during the period covering 1971-1985. Floods partially or completely destroyed 14.5, 14.2, 27.1 and 10.3 percent of the total t.aman acreage in the East, Central, Southwest and Northwest regions, respectively (see Table 3). Although much of the damage occurred in the lowlands, abnormally high water levels in the medium highland areas also caused considerable loss in HYRVs planted there. This provided valuable, but costly, information to farmers about the sensitivity of HYRV t.aman to high water levels; convincing many farmers of the superiority of taller traditional varieties in escaping, or at least tolerating unpredictable seasonal floods. Much of the medium- and high-land HYRV t.aman in 1973 shifted back into traditional varieties in subsequent years, as the data shows. This effect was further reinforced by another sweep of damaging floods in the following year, 1974, again causing substantial losses in t.aman production. Since farmers gain their greatest experience, and most valuable information with regard to performance of HYRVs in particular land types, during years in which significant flooding damage occurs, the largest adjustments can be expected immediately following that time.

Accordingly, it was felt that introduction into the basic logistic function of two crop damage variables-- D_{t-1} and D_{t-2} (percent t.aman acreage damaged by floods in year t-1 and t-2, respectively) would have a significant effect on rate of adoption

and may help explain the overadoption and adjustment periods mentioned above. Use of lagged t.aman area damage (D_{t-1}) was necessary because information about HYRV performance under flooded conditions in year t would not have an effect on t.aman planting decisions until year t+1. We would expect a negative sign associated with this variable: the greater and more extensive the damage to t.aman acreage, the greater the likelihood of farmers shifting back from HYRV to the taller traditional variables. It is also important to include D_{t-2} in the equation to account for either (a), a delayed effect in adjusting (downward) in response to t.aman acreage damaged, or (b), to allow for an overadjustment occurring in lag period t-1, and thus a readjustment upwards (increase in HYRV adoption) in the second year. Case (b) is consistent with risk averse behavior: a sudden dramatic decrease in HYRV use in year directly following a major flood, followed by a readjustment in HYRV in the second year. We would expect a negative sign associated with the parameter in case (a), a positive sign associated with the parameter in case (b).

Both of these variables have been divided by t, and we write them as D^*_{t-1} (= D_{t-1}/t) and D^*_{t-2} (= D_{t-2}/t). Dividing by t is an indirect way of accounting for the learning experience (associated with HYRVs) which we would expect to decrease with

time. Eventually as t goes to infinity, we would expect the crop damage variables to have no effect on rate of adoption[6].

Next we consider price variables to capture profitability differentials. Yearly data on profitability differentials for HYRV and traditional variety technology were not available. Both the Griliches and Jarvis study confirm the importance of this variable in explaining the rate of diffusion of a new technology. In lieu of this, two price ratio variables thought to influence the year to year profitability differential, one directly, the other indirectly, were incorporated into the model.

The first is the traditional variety and HYRV t.aman price ratio (T/H). An increase in the price of traditional variety rice, relative to that of the HYRVs is expected to be associated with a reduction in acreage sown to HYRVs[7]. Economic theory, therefore, suggests a negative sign for this coefficient. The other variable is the rice-jute price ratio (R/J). Jute and aus rice are competing crops, and both are often followed by t.aman.

---

[6] This is a somewhat arbitrary weighting procedure, but nonetheless, an intuitively acceptable one. One cannot assume that t.aman flood damage per acre has a constant effect on farmers' planting decisions year after year. For example, the amount of information obtained from events in 1973, in which floods destroyed, say, ten percent of the acreage in a region, has a much greater impact on farmers' decisions in the following year than would a similarly destructive flood occurring in 1983 in affecting the same decisions. Ideally, a time-dependent variable coefficient could be estimated for this. In view of our limited amount of data, a simple discounting system-- dividing the acreage damaged by the year t in which it occurred, was considered preferable.

[7] On the average, the price of HYRV grain, due to its inferior quality, tends to be about 80 percent that of the traditional varieties.

Although jute and aus tend to be planted around the same time, the main jute crop tends to be harvested two to three weeks later than aus. This means that t.aman following jute tends to be planted a little later than following aus rice, thereby favoring the use of traditional varieties. This is because HYRVs suffer proportionately greater yield loss than traditional varieties with delayed plantings. Theoretically then, increased jute production should be negatively correlated with HYRVs. This suggests a positive sign on the coefficient for this variable R/J. Note that both these price ratios, T/H and R/J, are used here as a proxy for the respective expected price ratios.

Defining

$$x'_t\beta = \beta_0 + \beta_1 t + \beta_2 D^*_{t-1} + \beta_3 D^*_{t-2} + \beta_4 (T/H)_t + \beta_5 (R/J)_t$$

and incorporating this into the logistic model expression in (4) gives

$$P_t = \frac{K}{1 + \exp-[\beta_0 + \beta_1 t + \beta_2 D^*_{t-1} + \beta_3 D^*_{t-2} + \beta_4 (T/H)_t + \beta_5 (R/J)_t]} \qquad (5)$$

Given this model we can easily find the impact of different variables on P_t, e.g.,

$$\frac{\delta P_t}{\delta (T/H)_t} = P_t \left(1 - \frac{P_t}{K} \right) \beta_4$$

Therefore, the respective coefficient of each variable determines the direction and relative magnitudes of the effect. However, the interpretation of the coefficients is not very

straightforward since the derivatives depend on the level of P_t.

Jarvis´ (1982) approach was similar, but he expressed the rate of diffusion directly as a function the exogenous variables which seems to be ad hoc. Let us start with the form (2) of the logistic function and write the relative growth rate as

$$\frac{1}{P_t}\frac{dP_t}{dt} = r_t \left(1 - \frac{P_t}{K}\right) \tag{6}$$

$$= r_t (1 - kP_t)$$

where $k = 1/K$ and r_t is a function of the exogenous variables. This model says the relative growth rate of adoption is a function of some economic variables and present level of adoption with respect to a potential ceiling level $(1 - P_t/K)$. When r_t = r (constant), we get the logistic model (1). Now we follow the standard derivation for the logistic curve to obtain an explicit form for P_t. Rearranging (6)

$$\left[\frac{1}{P_t} + \frac{k}{1-kP_t}\right]\frac{dP_t}{dt} = r_t$$

$$= \beta_0 + \beta_1 t + \beta_2 D^*_{t-1} + \beta_3 D^*_{t-2} + \beta_4 (T/H)_t + \beta_5 (R/J)_t$$

Integrating with respect to time t,

$$\ln P_t - \ln(1-kP_t) = \alpha_0 + \beta_0 t + \beta_1 (t^2/2) + \beta_2 D_{t-1} \ln t + \beta_3 D_{t-2} \ln t$$
$$+ \beta_4 (T/H)_t t + \beta_5 (R/J)_t t$$

where α_0 is a constant of integration. After simplifying, we

have

$$P_t = \frac{K}{1+\exp-[\alpha+\beta_0 t+\beta_1 (t^2/2)+\beta_2 D_{t-1} \ln t+\beta_3 D_{t-2} \ln t+\beta_4 (T/H)_t t+\beta_5 (R/J)_t t]} \quad (7)$$

where α is a constant. Model (7) can be viewed as a combination of the modified logistic model (5) and the Jarvis model. Once we know the coefficients of model (7), we can calculate that part of the relative growth rate which is not explained by the logistic model. As in model (5), it will be difficult to isolate the effect of t on P_t, since t enters several of the variables. However, we can judge the relative impact of each variable from the respective coefficients. Models (5) and (7) are non-nested in the sense that neither is a special case of the other and one cannot be obtained as an approximation of the other. At the outset, there are no economic reasons to prefer either model. After estimating both the models, we will apply a non-nested hypothesis test procedure and information criteria to judge the relative merits of the two models.

6. Estimation Results for Bangladesh

Coefficient estimates of models (5) and (7), denoted by Models 1 and 2A, using aggregate Bangladesh data are found in Table 4. The high R^2s obtained suggest good fits for both models. DW statistics are also of reasonable magnitude. We also

report statistics[8] (denoted by NT) to test normality of the regression residuals. For Model 2A normality is accepted but in Model 1 non-normality is evident.

A comparison between these two models and the logistic model reported in Table 2 establishes the importance of modifying the simple logistic function to accomodate variables which significantly affect the information and learning process (D_{t-1}, D_{t-2}) and which influence expectations about profitability (T/H, R/J). The most interesting coefficient estimate is that of the ceiling level K. Model 2A predicts a value of 23.66 (i.e., only 23.66 percent of the total t.aman acreage will ever find its way into HYRVs). This value was reached as early as 1981, indicating no remaining potential for HYRV t.aman expansion in Bangladesh. Model 1´s predicted K value is slightly higher (24.43) but that level too has almost been reached. This finding is contrary to the common belief that the adoption rate will continue to rise, reflected in the high target levels set up by agricultural and government planners. Such targets are unrealistic without some

---

[8] The test statistic combines skewness and kurtosis for testing normality, specifically,

$$NT = n\left[\frac{(\text{skewness})^2}{6} + \frac{(\text{kurtosis} - 3)^2}{24} \right]$$

where n is the sample size [see Jarque and Bera (1987)]. Under the normality hypothesis, NT is asymptotically distributed as a central X^2 (chi-suare) with two degrees of freedom. Since our test statistics are based on only a sample of size 15, asymptotic X^2 critical values could not be used. The appropriate critical values will be slightly lower than those reported in Jarque and Bera (1987) for n=20 (2.13 and 3.26 at 10 and 5 percent siignficance levels, respectively).

change in infrastructure or development of new HYRVs with wider adaptability[9].

Expected signs were observed for all the coefficients in Model 1, and the t-statistics were signficant to the .05 level for all coefficients except for the D^*_{t-2} variable. The positive (but insignificant) sign on this coefficient suggests a readjustment process upwards in the second year following a major flood, indicative of risk averse behavior. The negative sign on the D^*_{t-1} coefficient, as expected, supports the hypothesis that adverse climatic conditions, such as major floods, due to their differential impact on HYRV and traditional varieties, have a negative impact on rate of HYRV adoption. Here we should also note the higher numerical magnitude of this coefficient compared to that for D^*_{t-2}. The lower coefficient value for the D^*_{t-2} variable (0.17 vs. -0.65), means that not all of the initial effect from flood damage (in fact, only about 30%) has been offset by this later readjustment. However, the actual impact of the D^*_{t-1} and D^*_{t-2} variables cannot be measured without respect to time t. The damage variables have their greatest effect in the

---

[9] One criticism with regard to the definition of the ceiling level or long-run equilibrium should be mentioned. Since it is true that HYRVs of t. aman are constantly being modified (or new ones being developed) and therefore overlapping in their adoption, the equilibrium levels may actually flow constantly, and thus, there may never be a unique ceiling level [Feder et al. (1985)]. This is a valid criticism if the new releases of HYRVs are specifically suited to areas formerly not covered by the HYRVs. This has not happened in Bangladesh, at least not on a significant scale. No new HYRVs have yet been developed for the drought or flood prone areas of Bangladesh. Thus, it remains a case of replacement, of one HYRV for another, rather than one of initial adoption.

early years of HYRV introduction, but as t increases, they have a reduced effect on P_t.

Signs of the coefficient values in Model 2A were as expected for all except the $(R/J)_t t$ variable. Student-t values, however, were insignificant for the time variable, the $D_t \log t$ variables, and the $(T/H)_t t$ variable. The most likely reason for this is problems associated with collinearity, since time is a component in each of these variables. Correlation coefficients of .99 and .80 were observed between the time variable t and $(T/H)_t t$ and $(R/J)_t t$ variables, respectively. The failure to adequately accomodate meaningful price ratio variables is a serious weakness of this model. A third model, a respecification of Model 2A, was therefore estimated in which the two price ratio variables were omitted. Results from this estimation (Model 2B) are also found in Table 4. Although the economic variables relating HYRV levels of adoption to profitability differentials are sacrificed, the model is preferred in the sense that t-values are in most cases more highly significant and the model is more parsimonious. Given the limited number of observations in the data, this is an important criteria. Estimates of the ceiling level K and the coefficient of $t^2/2$ (comparable to the coefficient of t in Model 1) did not change much in the respecified model.

Given the results of Models 1 and 2B, it is difficult to choose one model: both have reasonably high R^2 values and, in general, correct expected signs. We use two other approaches for model selection: information criteria and non-nested testing.

The results from the three information criteria AIC, BIC and HQ are given below [see Judge et al. (1985, pp. 870-872) and Hannan and Quinn (1979)].

	Model	
Criteria	1	2B
AIC	60.996	48.630
BIC	64.951	52.020
HQ	66.778	53.586

On the basis of these selection criteria Model 2B is preferred. Next, we applied the Davidson and MacKinnon (1981) J-test to Models 1 and 2B. In this test, when we test Model 1 against Model 2B, prediction from 2B is used as a new variable in Model 1 and its significance is tested. If it is significant we reject Model 1. The procedure is similar when we test Model 2B against Model 1. Application of these tests resulted in rejection of Model 1, but failure to reject Model 2B. Here we should note, however, that the J-test is an asymptotic test and for our small sample the outcome of the tests may not be very reliable. Nonetheless, given these results, and our earlier outcome from the normality test, it appears that Model 2B is the preferred model.

It would be interesting to look at dP_t/dt, the growth rate of adoption, at different time periods. Since damage variables are not a function of t, this is equivalent to $\delta P_t/\delta t$, which for Model 2B (equation (7) without the two price ratio variables) is given by

$$\frac{1}{K} P_t(K-P_t)\ [\beta_0 + \beta_1 t + \beta_2(D_{t-1}/t) + \beta_3(D_{t-2}/t)]$$

Using the coefficient estimates and the predicted values of P_t, the estimated growth rates are as follows:

Year	Growth Rate	Year	Growth Rate
1973	-2.28	1980	2.57
1974	-1.79	1981	0.43
1975	6.05	1982	0.00
1976	11.35	1983	0.00
1977	17.05	1984	0.00
1978	20.40	1985	0.00
1979	11.90		

Only in the two earliest years, 1973 and 1974, are the rates negative--- clearly reflecting the effect of the damage (see Table 3). Highest rates occur from 1976 to 1979 when the modified logistic curve is steepest. The effect of time on the rate of adoption diminishes as P_t approaches K, and eventually reaches zero.

7. Regional Model Estimates

Coefficient estimates of Models 1 and 2B for each of the four regions appear in Table 5. In most cases R^2 values were high; however, some of the DW statistic values were very low. Attempts were made to correct for serial correlation using a first order process, but that resulted in many of the t-statistics being insignificant. This may have been because of

the limited data[10] available and/or because the first order process was not the correct autocorrelation structure. Therefore, this may limit the degree of reliability of these results. Problems associated with non-normality were evident for the Central and East regional models in Model 1, but only for the Central region in Model 2B.

Considering the results from Model 1 first, we note that all of the coefficients in the East and Southwest regional models, all but one in the Central model, and four (of seven) in the Northwest regional model, had their expected signs. None of the t-values, however, for these "wrongly" signed coefficients were significant at the .05 level. Nonetheless, the model did not appear to explain Northwest region data adequately. Only the t-statistic for K was found to be significant. In contrast, the East and Central regional model estimations appear to be quite satisfactory. Highly significant t-values for K, the slope (or time) coefficient, the lag crop damage coefficient and the rice-jute price ratio coefficient were found for all three regional estimates. Model 2B also had good results for the regions although there were a few unexpected signs.

The β_1 slope values, which represent the rate of acceptance (or diffusion rate) in Models 1 and 2B, vary considerably between the regions. The Central Region had a significantly steeper

---

[10] Little can be done to correct for this since collection of data on HYRV acreage in Bangladesh was not initiated until 1971 (HYRVs were introduced only in 1968). Thus, until more data can be obtained from future years, this kind of limitation must be accepted.

slope than the East Region (for Model 1, 1.47 vs. .33 and for Model 2B, 1.02 vs. .26), in spite of its lower K estimate. This was due mainly to the shortness of time it took to achieve its K value (as early as 1980). The higher β_1 value observed for the Central Region (followed by the Southwest, Northwest and East regions, respectively) means that the awareness gap and experimentation period is shorter, on average, for these farmers than it is for farmers in other regions [Rogers (1983)]. This is quite plausible since this region includes the capital city, Dhaka, and many of the agricultural research institutions in the country. A higher level of general awareness about new technology, better communication and information flow, and better access to necessary inputs, may all contribute to their more rapid HYRV acceptance rate. Griliches has also asserted that diffusion rates are related to the environment. A more favorable environment (better soil and water availability) increases the expected utility of income from use of the new technology, and thus increases the probability that farmers will adopt. But, as noted below, this may play a more important role in determining K values. As mentioned earlier, estimates of β_1 in Model 1 (coefficient of t) and Model 2B (coefficient of $t^2/2$) are comparable. Except for the Northwest region their relative magnitudes are the same. However, in Model 1, estimate of β_1 for the Northwest region is not reliable, due to the poor fit.

For the R/J variable in Model 1, all four regions had a positive coefficient estimate, and t-values for all except the

Northwest region were significant. This is consistent with expectations and thus confirms the indirect relationship between the aus-jute crop choice and the subsequent choice of HYRV t.aman. The differences in the magnitude of the response can be seen from the table. The Central region appears to respond the most to aus-jute price differentials with respect to HYRV t.aman. Lastly, as expected, for both models D_{t-1} has the negative sign for most cases, however, there are substantial regional differences.

From the estimated K values, it is apparent that little scope for increased production through expansion of t.aman HYRVs acreage currently exists. All of the regions have reached, or almost reached, the ceiling level of their asymptotic curves. According to Model 1, it appears some slight potential remains in the East region. Model 2B shows no potential left for HYRV acreage expansion.

	Model 1			Model 2B		
	Predicted P_t 1981	Predicted P_t 1985	Estimated K	Predicted P_t 1981	Predicted P_t 1985	Estimated K
East	52.33	54.02	55.51	52.22	52.98	52.98
Central	32.92	32.92	32.92	32.98	32.98	32.98
Southwest	14.81	14.94	14.94	15.00	15.00	15.00
Northwest	16.89	18.22	18.24	12.65	19.55	19.61
Bangladesh	22.05	24.07	24.43	23.42	23.52	23.52

The Central region reached its ceiling value by 1980 (32.92), the Southwest region by 1984 (14.94 percent), and the Northwest region in 1985 (18.24 percent). The relatively lower adoption

ceiling levels (K values) obtained for the Southwest and Northwest regions suggests poorer soil and landtype suitability for HYRVs of t.aman. The two most serious biological constraints facing HYRVs adoption are deepwater intolerance and drought sensitivity. It is precisely in those two regions where these conditions are most widespread: the Northwest, where low rainfall and drought limits HYRVs diffusion, and the Southwest, where deep flooding hinders not only HYRVs but also total t.aman acreage itself. On the other hand, in the East region, and to some extent in the Central region, better land suitability (less flood prone) and higher rainfall (less drought susceptibility) make it a more ideal environment for HYRVs, thus leading to higher values of K.

With little potential left for HYRV t.aman acreage expansion, there is only limited scope for increased rice production through futher adoption of HYRV t.aman unless new HYRVs are developed with wider adaptability--- especially for drought and flood prone areas, where so much of the ultimate potential actually exists. In this respect, Bangladesh is indeed a challenging environment for new HYRV development. It has the largest proportion of area with deepwater rice (greater than 3 feet) and intermediate deepwater rice (12 - 40 in.), areas currently not suitable for HYRVs [Huke (1982)]. Evidence from this analysis indicates that if increased production is to be realized through HYRV t.aman acreage expansion, greater emphasis will have to be given to developing varieties tolerant to drought

or flooding. Despite their obvious importance, breeding for tolerance to adverse environmental conditions, particularly flood and drought, has received little attention [Barker et al. (1985)].

8. Conclusions

This study develops a model to explain aggregate adoption of HYRV t.aman acreage for Bangladesh and the four regions within Bangladesh for the period 1971-1985. The results of this study, similar to Griliches´, point to the importance of location specificity in characterizing the pattern of adoption of new rice varieties. This is because the parameters associated with the diffusion of the new technology, depend upon the extent to which the technology suits the conditions under which farmers operate. Thus differences in diffusion of HYRV t.aman among regions is expressed in terms of ceiling level, rate of acceptance, overadoption and adjustment, and profitability differentials as measured in price ratios. We also demonstrate the importance of incorporating explanatory variables into the simple logistic model to more effectively characterize aggregate adoption behavior. Especially critical is knowledge about adverse climatic events to explain radical departures from the logistic curve, such as when mass discontinuance occurs.

This study has important policy implications. Despite the Bangladesh Rice Research Institute´s target projection of reaching 60 percent HYRV acreage adoption by 1990 [Bangladesh

Agricultural Research Council (1983)], further increases in rates of adoption, at least on any significant scale, are unlikely to occur. From a practical standpoint, crop production increases through HYRV t.aman acreage expansion presently appear quite constrained. Unless new HYRVs are developed with wider adaptability, especially for drought and flood prone areas, little scope exists for increase HYRV t.aman area expansion. In this respect, HYRV technology ought to be designed in accordance with the physical and economic environment in which farmers operate. Relevant variables which have a significant impact on HYRV use, and which vary from area to area or district to district, suggest the need to tailor technology development to particular regions rather than to the whole country.

Acknowledgements:

We would like to thank Professors Pravin Trivedi and Laurian Unnevehr for their helpful comments on an earlier draft of this paper. Financial support from the Program in South and West Asian Studies, the Research Board and the Bureau of Economic and Business Research of the University of Illinois is gratefully acknowledged.

References

Bangladesh Agricultural Research Council, 1983, Agricultural research in Bangladesh: Contributing to national development (BARC, Dhaka, Bangladesh).

Bangladesh Bureau of Statistics, 1982, 1981-82 Agricultural yearbook of Bangladesh (Ministry of Finance, Govt of Bangladesh, Dhaka, Bangladesh).

----- 1984, 1983-1984 Agricultural yearbook of Bangladesh (Ministry of Finance, Govt of Bangladesh, Dhaka, Bangladesh)

----- 1986, Monthly statistical bulletin of Bangladesh, March 1986 (Statistics Division, Ministry of Planning, Govt of Bangladesh, Dhaka, Bangladesh).

Barker, R., R.W. Herdt and B. Rose, 1985, The rice economy of Asia (Resources for the Future, Washington D.C.).

Dalrymple, D.G., 1986, Development and spread of high yielding rice varieties in the less developed countries (Agency for International Development, Washington D.C.).

Davidson, R. and J.G. MacKinnon, 1981, Several tests for model specification in the presence of alternative hypotheses, Econometrica 49, 781-793.

Diamante, T. and J.C. Alix, 1974, An analysis of crop shifting and farm practices of IAS sample farmers in the Philippines (Res. Rep. 3, Bureau of Agricult. Economics, Quezon City).

Feder, G., R.E. Just and D. Zilberman, 1985, Adoption of agricultural innovations in developing countries: A survey, Economic Development and Cultural Change 33, no. 2, 255-298.

Feder, G. and G.T. O´Mara, 1982, On information and innovation diffusion: A bayesian approach, American Journal of Agricultural Economics 64, 145-147.

Food and Agriculture Organization of the United Nations, 1984, Contingency crop planning to obviate adverse effects of aberrant weather conditions: Bangladesh context (FAO, Rome).

Griliches, Z., 1957, Hybrid corn: An exploration in the economics of technological change, Econometrica 25, 501-522.

Hannan, E.J. and B.G. Quinn, 1979, The determination of the order of an autoregression, Journal of Royal Statistical Society, Series B, 41, 190-195.

Huke, R.E., 1982, Rice area by type of culture: South, Southeast, and East Asia (International Rice Research Institute, Los Banos, Philippines).

Jarque, C.M. and A.K. Bera, 1987, A test for normality of observations and regression residuals, International Statistical Review, 55, no. 2, 163-172.

Jarvis L.S., 1981, Predicting the diffusion of improved pastures in Uruguay, American Journal of Agricultural Economics 63, 495-502.

Judge, G.G., W.E. Griffiths, R.C. Hill, H. Luetkepohl and T-C Lee, 1985, Theory and practice of econometrics (John Wiley and Sons, New York).

Leuthold, F.O., 1967, Discontinuance of improved farm innovations by Wisconsin farm operators, PhD dissertation (University of Wisconsin, Madison).

Ministry of Planning, 1985, Third five year plan 1986-1990 (Govt of Bangladesh, Dhaka, Bangladesh).

Rogers, E., 1983, Diffusion of innovations (Third Edition, The Free Press, New York).

Table 1. Percent of Total T. Aman Acreage Planted to HYRVs, 1971-1985.

	Region				
Year	East	Central	Southwest	Northwest	Bangladesh
1971	8.51	9.94	5.53	6.19	6.96
1972	20.30	19.83	10.78	12.43	14.52
1973	31.79	27.91	11.35	21.29	21.28
1974	21.77	12.45	7.54	13.83	13.15
1975	27.04	19.86	9.32	10.68	14.17
1976	28.74	15.30	4.33	5.90	10.40
1977	30.58	20.32	4.83	5.15	12.21
1978	36.26	31.12	10.87	7.25	16.63
1979	43.59	29.34	12.89	11.91	19.91
1980	52.83	33.34	12.86	11.93	21.55
1981	53.82	32.52	13.35	12.06	21.58
1982	54.69	36.35	16.32	15.02	24.14
1983	51.02	31.45	15.99	16.86	23.42
1984	51.75	33.55	16.28	18.34	24.12
1985	51.60	33.93	15.96	20.93	25.21

Table 2. Estimated Logistic Curves for HYRV T. Aman Aggregate Adoption for Four Regions in Bangladesh.

Region	Parameter K	α	β	R^2	DW	Number of Iterations
East	58.97 (11.07)	-1.44 (5.98)	.27 (4.57)	.890	1.29	15
Central	40.85 (4.14)	-0.87 (2.78)	.19 (2.00)	.687	1.92	15
Southwest	no convergence					300
Northwest	no convergence					300
Bangladesh	19.09 (14.20)	- 2.47 (0.92)	1.89 (1.02)	.316	0.47	14

Note: Numbers in parentheses are t-statistics.

Table 3. Percent T. Aman Acreage Partially or Completely Damaged by Floods 1971-1985.

Year	East	Central	Southwest	Northwest	Bangladesh
	Region				
1971	0.00	0.00	3.17	0.93	1.23
1972	0.00	0.00	0.00	0.85	0.23
1973	14.47	14.16	27.10	10.26	8.48
1974	4.63	4.11	7.36	1.12	2.28
1975	2.81	0.00	0.00	0.00	0.18
1976	0.54	0.00	0.00	0.87	0.11
1977	0.00	2.16	0.00	2.51	0.79
1978	0.00	0.00	0.23	0.25	0.10
1979	0.00	3.36	0.00	0.00	0.57
1980	0.00	6.83	0.20	2.89	1.85
1981	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.64	0.74	0.31
1983	2.55	10.48	0.43	2.87	2.16
1984	0.00	1.43	0.00	5.77	1.83

Table 4. Estimated Coefficients for Modified Logistic Curves for HYRV T. Aman Aggregate Adoption in Bangladesh.

Model	Parameters/Variables									
	K	β_0	t	D^*_{t-1}	D^*_{t-2}	T/H	R/J	R^2	DW	NT
1	24.43	18.01	0.48	-0.65	0.17	-18.64	2.07	.910	2.19	5.62
	(18.56)	(2.44)	(3.40)	(3.14)	(1.40)	(2.83)	(3.06)			

Model	Parameters/Variables										
	K	α	t	$t^2/2$	D^{**}_{t-1}	D^{**}_{t-2}	(T/H)t	(R/J)t	R^2	DW	NT
2A	23.66	4.10	0.41	0.60	-0.02	0.07	-2.08	-0.20	.969	1.76	1.98
	(39.16)	(3.75)	(0.09)	(4.33)	(0.32)	(2.05)	(0.65)	(2.02)			
2B	23.52	3.63	-1.90	0.48	-0.08	0.05			.959	1.53	0.44
	(48.81)	(5.05)	(4.84)	(4.65)	(1.72)	(1.87)					

Note: $D^{**}_{t-1} = D_{t-1}$ lnt; $D^{**}_{t-2} = D_{t-2}$ lnt; and numbers in parentheses are t-statistics

Table 5. Estimated Coefficients for Modified Logistic Curves for HYRV T. Aman Aggregate Adoption in the Four Regions of Bangladesh.

Model 1

Region	K	β_0	t	D^*_{t-1}	D^*_{t-2}	T/H	R/J	R^2	DW	NT
	Parameters									
East	55.51	-0.96	0.33	-0.23	0.01	-1.17	1.10	.958	2.04	5.84
	(17.24)	(0.69)	(3.52)	(3.48)	(0.16)	(1.09)	(2.61)			
Cent	32.92	-30.74	1.47	-1.26	0.27	12.25	8.72	.961	2.51	8.94
	(57.67)	(1.84)	(2.71)	(5.23)	(2.72)	(0.83)	(4.64)			
SWest	14.94	2.04	1.03	-0.33	0.28	-11.22	4.95	.919	0.86	0.82
	(29.42)	(0.27)	(3.73)	(3.81)	(3.16)	(1.59)	(4.20)			
NWest	18.24	-29.14	0.79	5.13	-0.39	16.50	2.59	.746	2.24	0.62
	(11.26)	(1.39)	(1.62)	(1.72)	(0.86)	(1.31)	(1.46)			

Model 2B

Region	K	α	t	$t^2/2$	D^{**}_{t-1}	D^{**}_{t-2}	R^2	DW	NT
	Parameters								
East	52.98	1.08	-0.81	0.26	-0.03	0.03	.981	1.75	2.21
	(72.67)	(4.94)	(5.33)	(6.34)	(1.63)	(2.40)			
Cent	32.98	4.55	-3.36	1.02	-0.04	0.09	.961	2.69	8.78
	(59.51)	(6.15)	(6.06)	(5.90)	(1.20)	(4.49)			
SWest	15.00	3.41	-2.67	0.74	0.02	0.05	.929	1.03	1.27
	(33.42)	(4.06)	(4.10)	(3.85)	(1.03)	(3.03)			
NWest	19.61	3.44	-1.42	0.26	-0.05	0.01	.841	0.95	1.05
	(10.72)	(2.52)	(2.56)	(2.28)	(1.64)	(0.14)			

Note: $D^{**}_{t-1} = D_{t-1}$ lnt; $D^{**}_{t-2} = D_{t-2}$ lnt; and numbers in parentheses are t-statistics.

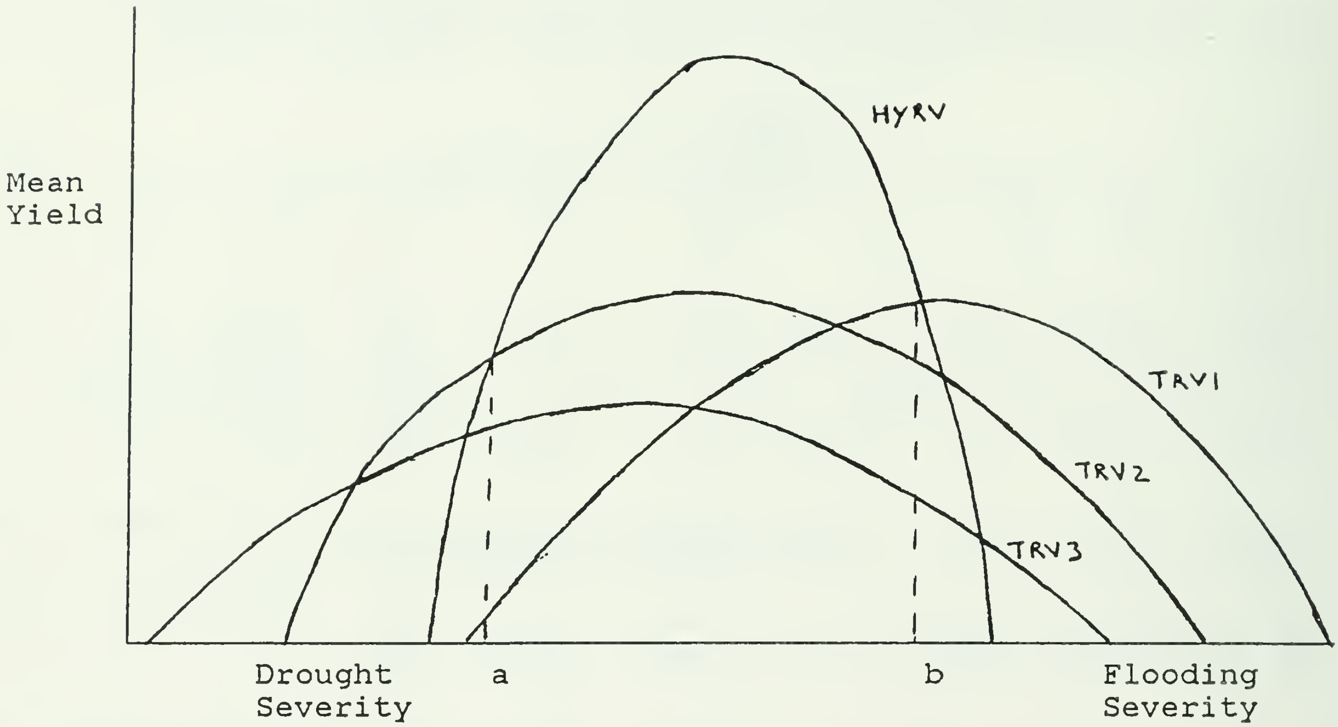

Figure 1. A simulated yield characterization of the predominant HYRV and different traditional varieties (TRV1, TRV2, TRV3) of t.aman under variable climatic conditions. Only between a and b are HYRVs yield-superior to traditional varieties.

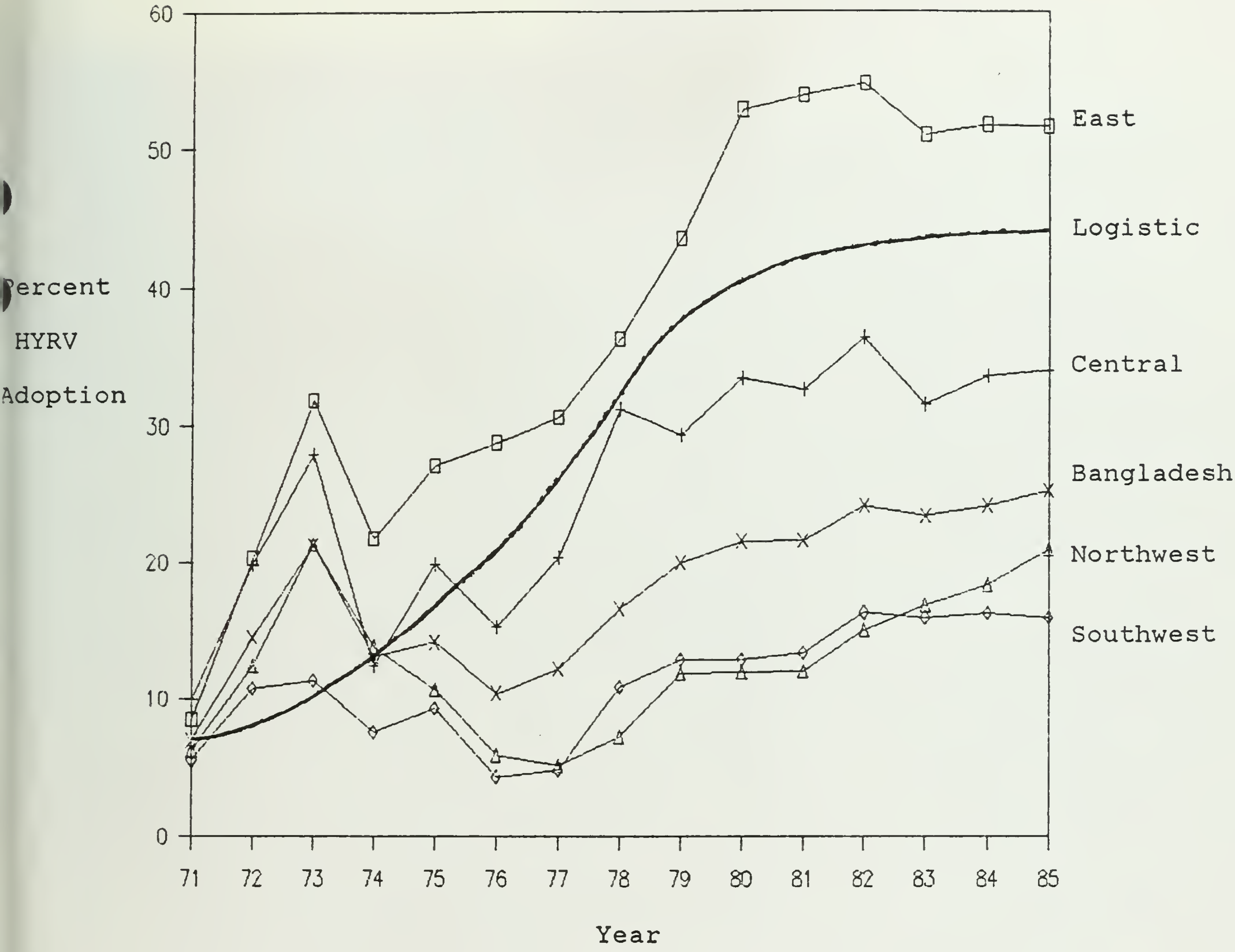

Figure 2. HYRV t.aman aggregate adoption curves for Bangladesh and the four regions, 1971-1985, and superimposed simple logistic curve.